Performance characteristics of a broad range ionization gage tube

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Seven commercial "broad-range" Bayard–Alpert ionization gage tubes were calibrated for N_2, Ar, H_2, D_2, and He. Between 10^{-4} and 10^{-1} Pa N_2 sensitivities varied between 3.2 and 4×10^{-2} Pa^{-1} (4.3 and 5.4 $Torr^{-1}$), as low as 52% of the specified sensitivity of 8 $Torr^{-1}$. Relative sensitivities of 0.16 ± 0.016 were obtained for He, and 0.37 ± 0.04 for H_2 and D_2. Sensitivities were determined at reduced emission for N_2 up to 1.4 Pa and 3 Pa for Ar. Argon sensitivities increased by up to 50% over this range. Voltage dependences were determined for changes in both the filament and grid bias voltages. These data showed an inexplicable grouping of the gage tubes into two distinct groups, one with small voltage coefficient typical of Bayard–Alpert gages, the other with much larger coefficients, such as expected from conventional triode gages.

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I. INTRODUCTION

Attempts to extend the linear range of Bayard–Alpert ionization gage tubes to higher pressures have been made by modifying the geometry and interelectrode field distribution, and consequently the electron and ion paths. One result is a commercially available "broad-range" ion gage tube. NBS recently calibrated a number of these gage tubes for use in a fusion system cryopump test. We took this opportunity to determine the nitrogen sensitivities of seven such gage tubes. As in a previous study,[1] this was done with the premise that the spread in sensitivities is a measure of the susceptibility of a gage design to the variability introduced by manufacturing tolerances and subsequent use, and the differences from the manufacturer's stated sensitivity gives a measure of the errors that can be expected when using uncalibrated gages. We also determined voltage coefficients for six of the gage tubes, again with the premise that consistency of voltage coefficients is a measure of the tolerance to variations in construction. Gage tube sensitivities at reduced emission current were obtained to higher pressures for both N_2 and Ar. Finally, sensitivities relative to that for N_2 were determined for He, H_2, and D_2 for two of the gage tubes.

II. GAGE TUBES

The gage tube, hereafter identified as the gage, differs from "conventional" B–A structures in that it employs a 12-mm-diam, 46-mm-long helical grid, and a platinum coating on the inside of the 41-mm-diam glass tube. The thoriated iridium filament and central collector are conventional. The large length-to-diameter ratio of the grid, approximately twice that of conventional B–A structures, is apparently designed to minimize axial drift of ions out of the collector region. The conductive coating is intended to control the electrostatic environment and maximize electron ionization paths.

The manufacturer's literature specifies a collector potential of 0 V, filament bias of + 30 V, grid bias of + 160 V, and shield potential of 0 V. Emission currents were not specified, but filament operating parameters were specified for 1 mA emission. This value was used for calibrations up to 10^{-1} Pa ($\sim10^{-3}$ Torr). Emission current of 13 μA was used for the high pressure calibrations. Nitrogen sensitivity is stated to be 8 $Torr^{-1}$, based on McLeod gage calibration of production standards.

All gages had 25-mm Kovar tubulations welded into high vacuum copper gasketed knife edge flanges.

All gages were new when mounted on the system. Except for a replacement gage mounted for the high pressure N_2 and Ar calibrations, all gages were operated between 400 and 450 h prior to obtaining the results presented in this paper. Most of this operation was at base vacuum, but included 10 calibrations with N_2, H_2, D_2, and He. At no time during this period (which preceded the high pressure calibrations) were gages exposed to pressures above 10^{-1} Pa. Of these early data only relative sensitivities for H_2 and He are reported for two gages. The other data were obtained for the various operating potentials of the commercial controllers used in the cryopump speed tests.

III. CALIBRATION APPARATUS

The calibration apparatus, described in more detail elsewhere,[2] is a 26-cm i.d. stainless steel cylinder with eight gage ports mounted in a symmetric arrangement. All components and seals are metallic. Stable pressures are generated by admitting a well-baffled flow of gas that is pumped out by a liquid nitrogen-trapped mercury diffusion pump through a 1-cm-diam orifice.

All gages were operated with NBS-designed controllers which permit adjustment and measurement of the emission current and all bias voltages. Filaments are operated with direct current with provision for switching the direction of the current.

Pressures in the calibration chamber are measured with a

magnetically suspended spinning rotor gage.[3] The gage was calibrated for nitrogen, argon, and hydrogen against a series expansion apparatus at the Physikalisch-Technische Bundesanstalt[4] below 0.7 Pa and against an NBS ultrasonic manometer[5] above 0.7 Pa. An accommodation coefficient of 1.03 was assumed for helium.[6]

IV. CALIBRATION PROCEDURES

The gages are mounted with the electrode axis vertical and exposed to free but not forced convection in a 23 °C ambient. The system is evacuated and baked at 230 °C for more than 18 h. Following baking, the tube filaments are energized and the tubes outgassed for 20–30 min with 8 A of current (manufacturer's absolute maximum rating) through the grids. The tubes are then operated at 1 mA emission and conditioned by operating with the calibration gas flowing at a pressure of 10^{-2} Pa for 1 to 2 h. This conditioning is repeated whenever the calibration gas is changed. Finally, the tubes are allowed to stabilize overnight at base pressures between 2 and 6×10^{-6} Pa (indicated N_2 pressure), the pressure depending on the history of the apparatus.

All sensitivities reported are relative to base conditons, i.e., the sensitivity

$$S=\frac{I^c-I_0^c}{I^e(P-P_0)},$$

where I^c is the collector current at pressure P, I_0^c is the collector current at base conditions, I^e is the emission current measured at the filament, and $P-P_0$ is the pressure change as measured by the spinning rotor gage relative to the base pressure P_0.

At the beginning of each calibration the gas handling system is flushed with the calibration gas and base collector current readings are obtained. Calibration pressures are generated by adjusting the setting of the leak valve and/or the gas reservoir pressure. Calibration pressures are always established in increasing order, starting with an initial pressure of about 10^{-4} Pa and increasing by factors of about 3.1 (two points per decade) to the final pressure. With nonreactive gases, pressures are generally stable within 0.1% after 5–10 min. Below 10^{-2} Pa the pressure will remain stable to better than 0.1% for 60 min or more. At higher pressures the limited volume of the gas reservoir causes a detectable decrease in pressure.

At each calibration point the emission and collector currents of each gage tube are read four times; twice with the filament current in one direction, twice with it reversed. Ion currents for the two different directions of filament current differed by from 1 to 9%, depending on the gage. The four readings are averaged to calculate the sensitivity. The order of readings is arranged so that the average readings for each gage corresponds to the time of the reading obtained from the spinning rotor gage. Even at the highest pressures this assures correspondence between gage and standard readings since the pressure change is slow and effectively linear. Typical time for a full set of gage readings is 10 min, time between pressures is 30 min.

V. UNCERTAINTIES

Uncertainties in the calibration system are discussed in detail elsewhere.[2] In summary, uncertainties in the electrical measurements are negligible except for a maximum $\pm$ 0.5% digital uncertainty in the electrometer readout. Gas impurities are less than 0.1%. Uncertainties due to pressure instabilities are negligible. Those due to spatial nonuniformity of the pressure are less than 0.1%. Random errors in the pressure measurements do not exceed the larger of 2×10^{-6} Pa or 0.1% of the measured pressure, evaluated at three times the standard deviation about the mean. Systematic uncertainties are estimated at 3% for N_2, 4% for H_2, 5% for He, and 6% for D_2.

The largest error, by far, was due to random variations in the gage sensitivities. While long term stabilities were not checked, repeated calibrations of six of the gages over a one month period with N_2 and H_2 showed sensitivity variations of $\pm$ 2 to 3% for two of the gages, $\pm$ 4 to 5% for two others, and instabilities to the point of being essentially inoperable at times for the remaining two. After these initial measurements one of the two most stable gages started periodically exhibiting rather systematic shifts as large as 18% before returning to its original sensitivity. Some of the effects of these random variations can be seen in the data presented below.

VI. RESULTS

Figure 1 illustrates N_2 sensitivities at 1 mA emission and manufacturer's recommended potentials for seven different gages. Five of the gages were calibrated together, the remaining two at a different time. The indicated percentage range is the deviation from the manufacturer's stated sensitivity of 8 $Torr^{-1}$. The previous study[1] and additional results obtained in this laboratory have revealed similar large deviations from nominal sensitivities for other types of B–A gages with thoriated iridium filaments. The change in sensitivity with pressure is basically monotonic except for two of the gages,

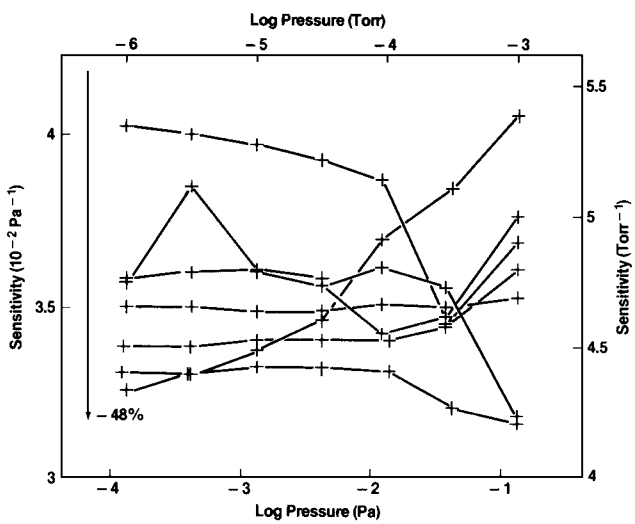

FIG. 1. Nitrogen sensitivities are shown for seven different gages calibrated at filament emission of 1 mA, filament bias of + 30 V, grid bias of + 160 V, and collector at 0 V. The 48% indicates the range of deviations from the manufacturer's stated sensitivity of 8 $Torr^{-1}$.

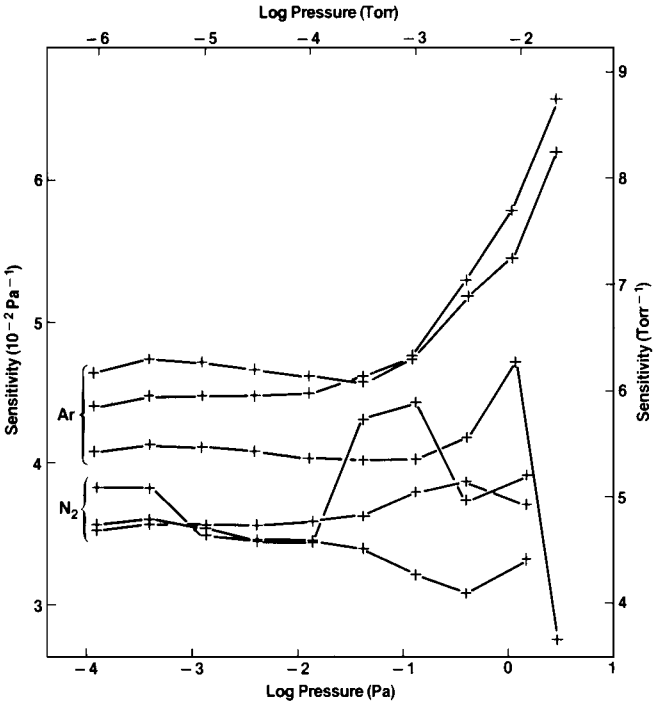

FIG. 2. Nitrogen and Ar sensitivities are shown for three different gages calibrated at filament emission of 13 μA, filament bias of + 30 V, grid bias of + 160 V, and collector at 0 V.

which show evidence of the instabilities discussed in the previous section.

Figure 2 illustrates the N_2 and Ar sensitivities for three of the gages at 13 μA emission and manufacturer's potentials. All three gages were calibrated at the same time. The gage with the erratic N_2 sensitivity had initially been relatively

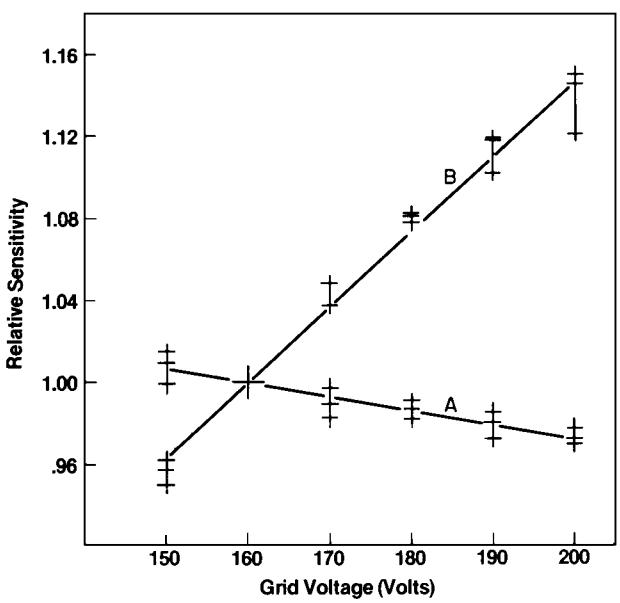

FIG. 3. Shown are the grid voltage dependences of six different gages with a constant filament bias of 30 V. Data were obtained at a N_2 pressure of 4×10^{-3} Pa and filament emission of 1 mA. Separation of the gages into the two distinct groups evident in this figure could not be correlated with other known properties of the gages except for the filament bias voltages dependences shown in Fig. 4. Group A: typical B–A behavior; group B: typical triode behavior.

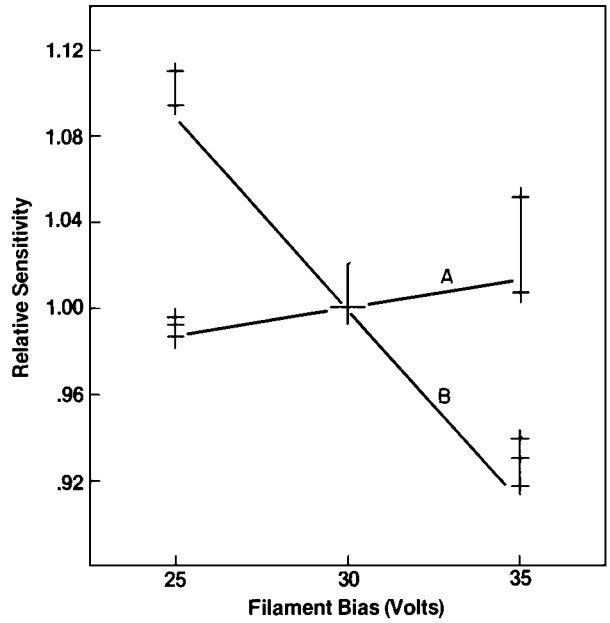

FIG. 4. Shown are filament bias voltage dependences obtained under the same conditions as the data shown in Fig. 3, except that the grid bias was held constant at 160 V. Group A: typical B–A behavior; group B: typical triode behavior.

stable, but exhibited rather large sensitivity shifts later in the tests. To within the limits set by random variations in the gage sensitivity no difference could be detected between the N_2 sensitivities at 1 mA and 13 μA emission. An additional Ar calibration point above 10 Pa was not included in Fig. 2 because of errors associated with unstable pumping speeds and pressures. However, these data did indicate a decrease in sensitivity for all three gages of approximately a factor of two.

Figures 3 and 4 illustrate voltage dependences for six of the gages. These data are remarkable in that the gages divide into two groups; those with the small coefficients typical of B–A structures, and those with much larger coefficients typical of what would be expected from a conventional triode structure.[2] This different behavior does not appear to correlate with time and place of gage purchase, i.e., there is no evidence this is due to variations between manufacturing lots, nor does it appear to correlate with the observed level of sensitivity stability.

Helium, H_2, and D_2 sensitivities were determined for two of the gages with 1 mA emission, filament bias of 30 V, and grid bias of 180 V, between 10^{-4} and 10^{-1} Pa. The bias voltages were chosen to agree with those used in determining relative sensitivities for other types of gages in our laboratory. We will note that in those other studies, with more stable types of gages, we have found the sensitivity for different gases relative to that for N_2 to be pressure dependent and, for B–A structures, gage dependent. In no case have we found a sensitivity difference between H_2 and D_2. However, for the broad range gages the random variations obscured any systematic differences that may be present. Therefore, we have averaged all of the data for both gages and, with an estimated uncertainty of $\pm$ 10%, find relative sensitivities of 0.16 ± 0.016 for He, and 0.37 ± 0.04 for H_2 and D_2. We have been unable to find relative sensitivities for this type of

gage in the literature to compare with these values.

The presence of the grounded shield outside the electrode structure undoubtedly has an important effect on the gage performance. Although we will not attempt to analyze that effect we will note the following observations: The shield current was monitored with an electrometer with a voltage offset of less than 1 mV. At 10^{-3} Pa of N_2 this shield current varied from 5.5 to 7.3 times the collector current for four different gages. As a function of pressure, the ratio for one gage varied from 5.7 at 10^{-4} Pa to 4.7 at 10^{-1} Pa. For He over the same pressure range for the same gage the ratio varied from 8.3 to 5.2. The shield current was observed to drop to about 1/3 the collector current when one of the gages became markedly unstable. When the shield of one gage was allowed to float up to filament potential during stable operation the collector current increased by 23%. We will further note a problem that we believe is related to the platinum coating. Following a H_2 calibration, maintenance was performed on the calibration chamber, during which air leaked in to an indicated pressure of 10^{-3} Pa. Following this the system was pumped back down but acceptable base readings could not be obtained until the entire system had been rebaked.

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